# REGIONAL-SCALE EVALUATION of PAST and FUTURE IMPACTS of CLIMATE and ENVIRONMENTAL CHANGES on RAINFALL-INDUCED LANDSLIDES



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## **1. Introduction**

According to the 5<sup>th</sup> Assessment Report climate, on landslides remains a complex of the Intergovernmental Panel on and challenging question. Moreover, also Climate Change, "*warming of the climate* land use and land cover (LULC), and their system is unequivocal". Global warming variations, affect landslide occurrence is recognized as potentially inducing and the related risk. substantial changes in climate system To face the problem, three linked (climate changes, CC) with relevant methods – quantitative and reproducible consequences on weather induced – for the regional-scale evaluation of past disasters, and in particular on slope and future variations in the occurrence of stability and landslides. An increase in rainfall-induced landslides, in response the frequency and the intensity of heavy to changes in climate (rainfall regimes) rainfall is expected in the Mediterranean and LULC, are proposed. The methods area. This might result in a variation in are based on detailed landslide the temporal and spatial distribution of information, weather and LULC data, and rainfall-induced landslides, and in an future projections related to increase in the size of the population Mediterranean region (Calabria, Southern exposed to landslide risk (Gariano & Italy). The methods adopt the municipal Guzzetti 2016). However, the quantitative boundaries as reference spatial units, but evaluation of the impact of global can be reapplied using diverse unit of warming, and the related changes in analysis.

## 2. Data

#### LANDSLIDE and RAINFALL EVENTS:

- catalogue of 7600 landslide events (LE) occurred in the period 1920-2010 in Calabria:

- daily rainfall records obtained by a network of 318 rain gauges in the same period, to reconstruct rainfall events (RE) - catalogue of 1466 rainfall events with landslides (REL), i.e. the occurrence in a given municipality of one or more LE during or after a RE.

Two criteria to single out the individual - Land Use map prepared in 1956 by CNR **REL: 1)** the geographical distance be- and the Italian Touring Club; tween the LE and the rain gauge location - CORINE Land Cover map released by where the RE is recorded shall be < 5 km; European Environmental Agency in 2000; 2) the date of the LE must be between the - ensemble of 32 simulations of the likely start and the end dates of the RE, or no LULC changes between 2000 and 2050 more than 1 day after the end of the RE.

#### **POPULATION:**

- data of inhabitants in each of the 409 - 2 climate projections based on RCP4.5 municipalities in Calabria measured by and RCP8.5 scenarios; national censuses made in 1951, 1981, - mean variations between a 30-year and 2011 (www.istat.it);

 demographic projections of population for the year 2065, from the Italian National Institute of Statistics (www.istat.it).



time windows.

#### **CLIMATE PROJECTIONS:**

future period (2036–2065) and the reference period 1981–2010 in 3 variables assumed as proxy for landslide activity: annual rainfall, seasonal cumulated rainfall, and annual maxima of daily rainfall.

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3. Looking back at the past Splitting the catalogue of REL in three **30-year periods (1921-1950; 1951-1980; 1981-2010)** and analysing the spatial and temporal variations of REL in the 409 municipalities of the region, we found that (i) the geographical and the temporal distributions of the REL have changed, (ii) the monthly distribution of the REL has changed, and (iii) the average and maximum cumulated event rainfall that have resulted in landslides in the recent **30-year period 1981-2010 are lower than** the rainfall necessary to trigger landslides in previous periods, whereas the duration Comparing the 2 Overall, 43% of the of the RE that triggered landslides has recentmost peri- population experiremained the same. We attribute these ods, IREL increased enced an increased changes to variations in the rainfall in 37 municipalities IREL OF RREL. conditions and to an increased (hosting 18.5% of vulnerability of the territory.

To investigate the impact (IREL) and the risk decreased in 47 (RREL) of REL on the population, and their (20.8% of populavaraitions, we compared the number of tion). RREL increased REL in each of the 409 municipalities in in 30 municipalities Calabria with the sizes of the population and decreased in (Pop) in the three periods. We used two 47 (24.0 and 19.1%) simplified formulas:

**R**<sub>REL</sub> = #REL × Pop IREL = #REL / Pop

Gariano et al. (2015)

## 4. Evaluating the impact of expected climate changes

occurrence of rainfall-induced landslides, of the relationships between the number in response to changes in rainfall regimes, of REL and the values of the climatic we used 603 REL and daily rainfall in the variables, and (ii) of the projected climatic period 1981–2010. Based on reliable scenarios. correlations between landslide occurrence Landslide Catalogue Rainfall Records and weather variables estimated in the reference period, we assessed future variations in rainfall-induced landslide occurrence for all the municipalities of Calabria.

We grouped the municipalities in classes with the same number of REL in the reference period, and we searched for a relationship between the number of REL in each class and the average values of the climatic variables, calculated for themunicipalities in the class. Finally, we calculated the projected future number of



the population) and of population, respectively).

To evaluate future variations in the REL in each municipality as a function: (i)





To evaluate the impact of past and future in the number of LE in each municipality, as land use/cover changes in landslide a function of the rates of change in LE occurrence at a regional scale, we used the occurrence related to LULC changes in the whole catalogue of LE in the period "past" and "future" observation periods, 1921–2010, and measures and projections of and of the projected LULC classes. LULC. We defined a common legend based on 15 classes between the 1965 land use map and the 2000 land cover map. We split the LE catalogue in two periods (1921-1965 and 1966-2010) and, per each period, we attributed to each of the 409 municipalities in Calabria: (i) a prevailing LULC class (which covered more than 50% of the area of the municipality with a terrain gradient >8.5°) and (ii) the number of landslides occurred therein in the period. Grouping the municipalities with the same attributed LULC in each period, we calculated the total number of LE in each LULC class, normalized by the total number of LE in the period. Then, we calculated the percentage variations, between the two periods, in the normalized number of LE occurred in each LULC class. We also calculated a density ratio to indicate a greater or smaller propensity to landsliding of each LULC. Finally, we calculated the projected changes



#REL = 0.03·MAR - 25.79 **Future Climate Projections Demographic Projection** Gariano et al. (2017)

A +45.7% and +21.2% average regional variation in rainfall-induced landslide occurrence is expected in the region for the period 2036–2065, under the RCP4.5 and RCP8.5 scenario, respectively. To investigate future variations in the impact of rainfall-induced landslides on the population of Calabria. We find a+80.2% and +54.5% increase in the impact on the population for the period 2036–2065, under the **RCP4.5 and RCP8.5 scenario, respectively.** 





### 5. Evaluating the impact of observed and expected land use/cover changes

**Expected average LE variation** 



**Using the defined relationships and 32** scenarios of projected LULC changes for the year 2050 (obtained considering all the possible combinations among: a moderate or strong degree of demographic increase; the existence or not of protected areas; the consideration or not of the spatial and temporal influence among land-use; two climate projections) we prepared 32 maps of projected variations in LE occurrence. All maps returned an increase in landslide occurrence, ranging from 0.9 to 3.2%. **Overall, a 2% increase in the number of** landslides is expected in Calabria by the

end of 2050, as a result of LULC changes.

#### 6. Conclusions

Results reveal a complex picture of the observed and expected changes in the occurrence of LE and REL in Calabria, and in their impact on the population. Regarding future changes, outcomes depend also on the elements of the simulation chain. Despite the results obtained under several scenarios are different, on average a regional increase in the occurrence of LE and REL has to be expected.

We maintain that the observed and expected variations in landslide occurrence and risk are due to changes in natural (landslide triggering and predisposing factors), environmental (land-use and land-cover) and societal (number and distribution of the exposed elements) components.

The proposed methods are objective and reproducible in similar regions, where adequate landslide, rainfall, and LULC information is available. The proposed method can also be applied to other geo-hydrological hazards, given the availability of the required information, and adopted for the design of effective adaptation strategies.

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Gariano et al. (2018)

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